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THE NATURE OF SOME SUPPOSED ALGAL COALS.

By Edward C. Jeffrey.

With Five Plates.

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Early in the last decade of the nineteenth century MM. Renault and Bertrand published simultaneously their views as to the constitution of so-called boghead and similar coals.[2] In the bituminous schists of Autun are apparent even to the naked eye glistening spherical or oval bodies often arranged in layers, which readily reveal themselves under the microscope, in thin sections made in the manner of the rock sections of the petrographer and mineralogist. These objects are of considerable size, their dimensions ranging between 189 and 225 micra in length and between 95 and 115 micra in breadth. They have been named on account of their shape and locality *Pila bibractensis.* The individuals of this species when examined microscopically sometimes show more or less clearly a central cavity, which is surrounded by a wall sculptured with numerous alveoli, opening to the outside but having no communication with the internal space. The two authors cited agreed in regarding these structures as representing the remains of colonial gelatinous green Algae. The central cavity, which always appears in the better preserved specimens, was regarded as the equivalent of the hollow space in the midst of a colony of the living Volvox, or an allied genus of the colonial Algae. The substance surrounding the cavity, according to the hypothesis of the French authors, represents the gelatinous wall of a former algal colony, while the external openings or alveoli are imagined to correspond in their position and relations to the once living individuals of the colony. The hypothesis of the algal nature of the organism found in such abundance in the bituminous schists of Autun, was later extended by its authors to a wide range of similar organisms occurring in bogheads and cannels, as well as bituminous schists and oil-shales from various parts of the world. Their most notable subsequent communications on this sub-

[1] Contributions from the Phanerogamic Laboratories of Harvard University, No. 23.

[2] Rénault, B., Communication faite sur le Boghead, Soc. Hist. Nat. Autun, 1892; Bertrand, C. E., *Pila bibractensis* et le Boghead d'Autun, Soc. Hist. Nat. Autun, 1892.

ject are as follows: C. E. Bertrand, *Reinschia australis* et Premières Remarques sur le Kérosene Shale de la Nouvelle Galles du Sud;[3] C. E. Bertrand, Les Charbons Humiques et les Charbons de Purins;[4] B. Renault, Sur Quelques Organismes des Combustibles Fossiles.[5] The contribution of Renault last cited is monumental in its character, representing as it does the labor of nearly a quarter of a century and dealing with most of the kinds of coal, which show structure when examined microscopically. Renault published from time to time, in the Bulletins of the Museum at Paris, his views as to the microscopic structure and related qualities of coal. Bertrand has recently written a very clear popular account of the views of Renault and himself.[6]

The ideas as to the constitution of certain coals cited above have not remained confined to their country of origin but have been adopted to a considerable degree in Europe and even in America. Professor Potonie, of the Royal School of Mines in Berlin, has taken up the Renault-Bertrand hypothesis and elaborated it in a number of publications. His views as to the origin of coal are stated with sufficient fulness in a pamphlet which has been of such general interest that it has gone through a number of editions.[7] Professor Potonie not only adopts the views as to the origin of boghead coals, oil-shales and bituminous schists advocated by the French authors cited above, but extends them to cannel coal, which Bertrand and Renault in common with other investigators have regarded as composed of the compressed remains of the spores of vascular cryptogams. The German author has gone further too than the French in describing recent peats which he supposes to be of algal origin and thus comparable with the bogheads and oil-shales of older geological periods. Dr. Davis White of the United States' Geological Survey has given not long since an admirably lucid account of recent views as to the origin of the various types of coal, including bogheads and oil-shales.

The present writer was led to investigate the subject of bogheads, oil-shales and other supposedly algal coals by reading the article of Dr. White cited above. In the investigations here described methods

[3] Bulletin de la Société, Hist. Nat. Autun, 1894.

[4] Travaux et Mém., Université de Lille, **6**, Memoir 21, 1898.

[5] Bulletin de la Société de l'Industrie Minerale, Serie 3, Tome 13, 4me. Livraison, 1899; Tome 14, 1re. Livraison, 1900, with atlas of 30 folio plate containing a large number of photomicrographs.

[6] Notions Nouvelles sur la Formation des Charbons de Terre, Revue du Mois, **3**, No. 15, pp. 323–41, Paris, 1907.

[7] H. Potonie, Die Entstehung der Steinkohle u. verwandter Bildungen einschliesslich des Petroleums. Vierte verbesserte u. erweiterte Auflage, Berlin, 1907.

have been used which admit of the securing of very numerous and even serial thin sections of the various coals studied. Previous observers have labored under the disadvantage of having to form their views from isolated and not very thin microscopic sections, obtained by the grinding methods of the lapidary. In the present research it has been found possible to adapt the more precise and delicate methods of the Biologist to the remains of organisms long extinct, which compose the mass of some of our most important if not most abundant coals. It will be well to give some account of the methods adopted before beginning the account of the observed facts.

Methods used in the Investigation.

It was found in all cases more advantageous to work with material softened by various treatments so that it could be cut successfully on the microtome. Control sections were used in many cases, prepared by the usual method, to make sure that the process of softening had not essentially modified the microscopic structures found in the various coals examined. The same process of softening was not found to be applicable to all kinds of coal. In the case of cannel or canneloid coals, treatment for a week or more with alcohol of seventy *per cent*, saturated with caustic soda or potash and kept at a temperature of from sixty to seventy centigrade, was found sufficient for the preliminary softening. After careful removal of the caustic alkali by repeated treatments with hot alchohol, it was generally found expedient to treat for two or three weeks with the strongest hydrofluoric acid. After washing out the acid, the small fragments of cannel are embedded in the usual way in Schering's celloidin and cut into thin sections on the sliding microtome. (The Jung-Thoma was found very useful for this purpose, on account of its rigidity.) The sections must in many cases be at least five micra thin. Thicker sections do not show details of structure with sufficient clearness nor can they be as advantageously photographed by the microscope as the thinner ones. In well-prepared material it is quite possible to cut serial sections of five micra. Individual sections thinner than five micra may be readily obtained. The preparation of serial sections has the advantage of making it possible to follow the structures observed through a number of sections, by which means their real nature can be more clearly and accurately elucidated.

In the case of the more resistent cannels and particularly in the case of those coals known as bogheads and oil-shales, more vigorous methods had to be adopted. It was found necessary to treat some of the American cannels and particularly American bogheads from Kentucky, with

aqua regia and in some cases with a similar combination of acids in which the hydrochloric acid was replaced by hydrofluoric. The last reagent is recommended as the most effectual one which has been found for softening and disintegrating even the hardest coals, such as anthracite, etc. In this fluid, both the nitric and hydrofluoric acid are used of full strength. The last method was found particularly advantageous in preparing the bogheads of Autun and the so-called oil-shale of New South Wales for microscopic examination. Sometimes it is an advantage to return the coals to alkaline alcohol after treatment with the various acids described. In such cases care must be taken to wash out all the acid and to thoroughly dehydrate the pieces of coal before transferring them to alkali in alcohol, as otherwise they suffer disastrous swelling. In all instances, no matter what devices were used for softening the coals, they were embedded in celloidin before cutting. The presence of any free acid or alkali in the material is disastrous to the knife in the first instance or to the consistency of the celloidin in the second. After the sections are cut they are dehydrated in a mixture of absolute alcohol and chloroform, to avoid softening the celloidin matrix. After clearing in benzole or xylol, they are mounted in balsam. In a few instances, such as the oil-shale of New South Wales, where the sections are very light colored, it was found advantageous to mount in glycerine jelly. In the case of serial sections, the best procedure is to lay the sections on a slide as they come off the microtome knife and then dehydrate and clear them carefully in their order. The usual methods of cutting celloidin series do not answer in the case of coal, as from the nature of the material frequently sections become folded or torn in transferring to glass. As not above four or five sections are ordinarily needed in series in a given case, to elucidate structural features, the method described above is not so laborious as it might appear.

The Structure of Cannel Coal.

It will be well as a preliminary to the observations on so-called algal coals (bogheads, oil-shales, bituminous schists, etc.) to describe the structure shown by ordinary cannel coal. It has long been known and has been made particularly clear by the monumental investigations of Renault, that what is usually known as cannel coal is composed very largely of the flattened spores of vascular cryptogams. Figure 1, Plate 1 shows the structure of cannel coal as seen in sections vertical to the layering in a moderately high microscopic magnification. The linear light bodies in the dark matrix are the flattened spores. The remains of the originally rotund central cavity can be seen as a dark

line. Figure 2, Plate 1, shows the same coal in section parallel to the planes of layering under the same microscopic enlargement. The spores appear in this plane in rounded outline and are much fewer in number. The explanation of the circular outline and the smaller number of apparent spores is afforded by the vertical section. In many cases it is possible in sections parallel to the layering of cannel to make out the presence of spores still in tetrads or in the case of isolated spores to distinguish triradiate ridges resembling those which mark contact surface of the reproductive bodies in many living vascular cryptogams. Some instances of these appearances are illustrated in the subsequent parts of this article, and need not be discussed here. The cannel just described is from Kentucky and is quite typical of the coals of this nature derived from this and other States. European cannels have also been studied but in general they show structure less clearly than the American cannels which have been examined. This is perhaps one of the causes of the apparent misinterpretations of some of the European writers on the microscopic structure of coal.

The Structure of Kentucky Boghead.

In most of the samples of cannel coal from Kentucky which have come under my observation, there occur, to a greater or less extent, bodies generally pale yellow in color but sometimes brown. These viewed in certain planes of section have the alveolar appearance, which is characteristic of the supposed Algae of Betrand, Renault, and Potonie. Those coals in which the imagined Algae become most abundant are known as bogheads, in accordance with the terminology of Renault.

It has been considered desirable in this connection to illustrate a boghead of unquestionable authenticity. I am indebted to Dr. David White of the United States' Geological Survey for some excellent material of Kentucky boghead of Pottsville age, which has been utilized in making the figures which are described in the paragraphs immediately following. A comparison with the figures and descriptions of Renault's monumental work show clearly that it is his *Pila kentuckyana* or a very closely allied species.

Figure 3, Plate 1, shows a number of the supposed Algae, denominated under the generic appellation Pila, somewhat highly magnified. They are variously grouped and scattered throughout the figure, a particularly striking clump appearing on the upper left hand of the figure. Most of the individuals show a mottled appearance, the dark spots corresponding in position to the supposed agal individuals con-

stituting the colony. Figure 4, Plate 1, shows a rather extensive field under a low magnification. On the dark background formed by the so-called fundamental substance of the coal may be distinguished various lighter areas, some of which figure as Algae, according to the Renaultian view, and others, even with the low magnification used, are of such a rounded or angular contour that they obviously represent the crushed remains of spores of the vascular cryptogams. The spongy or mottled light bodies represent the supposititious Algae. As will be shown later, the two kinds of appearances belong together, and only the absence of thin serial sections could have prevented the distinguished French author, cited above, from recognizing this state of affairs. Figure 5, Plate 1, shows part of the field reproduced in the foregoing figure, on a considerably higher scale of magnification. Figure 6, Plate 1, shows a little above the horizontal middle line two bodies, which are obviously cryptogamous spores. The one on the right partakes of the spongy or mottled appearance, presented by the supposed Algae. Elsewhere, especially in the lower part of the figure, are seen the remains of additional bodies, which take their place among the reputed Algae of Renault. Figure 7, Plate 2, shows part of the last figure more highly magnified to bring out more clearly the structural features of the bodies represented in the foregoing figure. In our next illustration, Figure 8, Plate 2, is represented another field under moderate magnification. On the right is a light body representing a fragment of some broken-up plant, a kind of remains with which both cannel and boghead coals abound. On the extreme left is seen a cluster of structures representing a tetrad of spores. In the median region of the figure are several of Renault's putative Algae. Figure 9, Plate 2, shows the tetrad from the left of the foregoing figure, somewhat mroe highly magnified. It is now apparent that on the extreme right of the tetrad one of the spores is cut through the back and the two anglewise plane surfaces. Another spore of the tetrad appears below and is obviously of the same nature as Renault's Alga *Pila kentuckyana*. The third visible member of the tetrad is less clearly seen on the upper side and is not so obviously of the organization represented by the supposed Algae. It will be well to defer the interpretation of the last figure until a number of other illustrations of the imagined Algae of Renault have been examined. Figure 10, Plate 2, represents a particularly striking view of a spongy or mottled mass, which at the same time from its contour and angles, is obviously the spore of a vascular cryptogam viewed from the plane of section through its angular internal face. The plane of section is so fortunate, in the compressed condition of the spore, as to show at the same time part of the alveolar

outer wall of the spore. In juxtaposition to the body, which is clearly a spore, are two of the putative Algae. In Figure 11, Plate 2, is shown another view of a spore-like body, there more obviously a spore. On the left is the projecting internal face of the spore, seen in section as an angle. The back of the spore is sculptured. In the remainder of the field are a number of the Alga-like bodies. The magnification in the present figure is about one half greater than in the last. Figure 12, Plate 2, represents, together with a number of the putative Algae, a body with the same alveolar parietal structure, which is at the same time obviously a spore. Figure 13, Plate 3, shows one of the spores so mumerous in the boghead coal under examination, in face view. The three ridges which mark the surfaces of contact with the three originally present sister spores of the tetrad can be very clearly made out. Such clear views of the spore face are comparatively rare, whether from the condition of compression of the spores or from the loss by decay of the thinner angular inner face of the spore, it is not easy to determine. The outlines of the spore in the last figure are rough, showing the alveolar nature of the free surface resembling that found in the spores of many of the existing Lycopodiales. Figure 14, Plate 3, shows in the center another spore in the same plan of section as that in the last figure. The magnification is very much higher for the purpose of bringing out the rough surface of the spore shown on the margins of the figure, particularly on the lower side. Above and below the central object are small portions of two other spores appearing as mottled alveolar structures. Figure 15, Plate 3, shows a complete tetrad of the spores under consideration in an oblique plane of section, which partially passes through the tetrad and partially reveals its free surface. Of three spores appearing in the section through the tetrad, two show at least part of their rough outer surface, while in case of the third none of this is apparent.

It will probably be apparent to the unprejudiced reader, from the figures of free spores and tetrads of spores in various planes of section already shown, that the supposed Alga, *Pila kentuckyana* of Renault, as figured in Figure 4, Plate 23, of his monograph, in reality represents sections through the rough alveolar surface of the reproductive bodies of vascular cryptogams. Although the conclusion thus indicated seems clear from the examination of reasonably numerous and well-prepared sections of coal containing the species under discussion, I have not allowed such evidence alone to suffice. As explained in the introduction, numerous serial sections were cut, in which it was possible to follow the appearance of the imagined Algae as well as the obvious spores as seen in successive planes. On account of the compression of

these objects, resulting from age-long pressure, coöperating with the softening effect of gradual decay, they are so thin that they rarely appear in more than two thin horizontal sections, more rarely in three. By the study of serial sections it was perfectly clear that the supposed Alga, *Pila kentuckyana* of Renault, and the obvious spores of vascular cryptogams, found in the same sections of coal, were different appearances presented by the same object. When only the free surfaces of the spores appear in the plane of section, as is more often the case, then their roughened exterior presents a mottled or alveolar appearance, which has been interpreted by a number of European observers in this and parallel cases as representing the bodies of gelatinous colonial Algae. When the angular or rotund aspects of the spores appear in section, their real nature is perfectly obvious. The error made by those who have been able to study only a few comparatively thick sections of the coals in question, results from not correlating the two sorts of appearances; an error scarcely to be wondered at from the nature of the preparations at their disposal.

The Structure of Scotch Boghead Coals.

The microscopic structure of the bogheads of Scotland is of particular interest because coals of this general type were earliest recognized here and the classic example Torbanite from Torbane Hill may be regarded as the original boghead, from the standpoint of scientific recognition. Through the kindness of Captain Baird G. Halberstadt, F. G. S., of Pottsville, Pennsylvania, I have had the opportunity of examining authentic material of a number of the Scotch coals of this group.

Figure 16, Plate **3**, shows part of a section parallel to the planes of layering in a boghead coal, so called, from the Armadale deposits, Bathgate, Linlithgow, Scotland. The magnification, which is moderate, reveals the presence of a number of bodies of a nature similar to *Pila kentuckyana*, described in previous paragraphs. Like *Pila kentuckyana*, they have an alveolar mottled appearance in certain planes of section, while in others they reveal a central cavity circular or angular in contour, as the case may be, and finally in some cases the bodies in question are grouped together in obvious tetrads or reveal the triradiate face characteristic of most Lycopodineous spores. All these conditions are revealed in the various parts of Figure 16, as may be ascertained by the use of a hand lens. Near the middle line of the figure above and below may be seen tetrads in various planes of section. Two of these in the upper and lower region of the photograph are par-

ticularly striking. Figure 17, Plate 2, shows two upper tetrads somewhat highly magnified. In the lower of these the alveolar structure of the walls of the spores is specially prominent, the plane of section being particularly favorable. There seems to be no reason for doubt that here we have to do with the structures from Scotch and other cannels, designated by Renault as *Pila scotica.* It is apparently beyond question from the few illustrations of this species which it has been thought necessary to introduce that in the case of *Pila scotica* as in that of the American species *P. kentuckyana* we have to do with spores of vascular cryptogams and not with anything approaching in the remotest way colonial gelatinous Algae. By the methods used in connection with the present investigation it has been found possible to secure large numbers of extremely thin section, which in case of doubt may be made serial. The large number of sections has made it feasible to choose those in which the supposed Algae are in the condition of tetrads, and thus reveal their nature as spores of vascular plants. Had the technique adopted here been available to Renault, there seems to be little doubt that he would have escaped the error of attributing the structures, which he designated *Pila scotica*, to algal affinities.

Among the various appearances present by the sections of Armadale coal are certain much larger spores, likewise not infrequently found in tetrads, and manifesting the same alveolar structure in certain planes of section through the spore wall as the species described above. These appear to be what Renualt described as *Thylax britannicus.*[8] It has not been thought necessary to illustrate these structures, as their identity as spores of vascular cryptogams is entirely beyond question.

Figure 18, Plate 3, shows a section vertical to the plane of layering of another coal from the Bathgate region, but not from the Armadale mine, for which the writer is indebted also to Captain Halberstadt. The organisms in this coal are much more numerous and are less well preserved than in the case of the so-called Pilas described above.

Near the center of the section but a little below on the right, is seen with unusual clearness one of the structures, which compose the coal at present under discussion almost to the exclusion of the so-called fundamental substance, which makes up the mass of the bogheads hitherto described. It can be made out that the structure in question is very much flattened but that the age-long pressure and chemical change have not obliterated the original central cavity. Less clearly marked cavities surrounded by less well-preserved walls are

[8] Op. cit., Pl. 21, figs. 1 and 2.

seen in several other instances in the section, while in the case of most of the organisms, the structure has suffered a good deal from the ravages of pressure and chemical metamorphosis. Figure 19, Plate 4, shows another section in the vertical plane of the same coal presenting somewhat similar appearances. This preparation, however, shows some of the bodies composing the coal in a darkened and chemically much modified condition, especially in the upper part of the field. Figure 20, Plate 4, represents a section through this boghead parallel to the planes of layering. Obviously some of the parts are better preserved than are others. In the well-preserved regions, which are distinguishable in figure by their lighter color, there is the same mottled appearance, which is characteristic of tangential sections of the spores known in the investigations of Renault as *Pila kentuckyana* and *P. scotica.* In the darker parts of the figure, the characteristic organisms of the coal have largely lost their structure and the accompanying swelling has almost completely obliterated the surface sculpture. Figure 21 illustrates another horizontal section of the coal under discussion, somewhat more highly magnified. On the upper left hand can be seen one of the constituting organisms of the coal in plane of section showing at once the profile and the face view of its wall. The profile view is the one sharply focussed and it presents all the appearance of a section through the wall of a macrospore of one of the existing Lycopodiales. In view of what has been learned regarding the structure of the American and Scotch species of Pila in the foregoing paragraphs, it can scarcely be doubted that the micro-organisms of the coal at present under discussion are also of the nature of spores of vascular cryptogams. The general arguments against the algal nature of these and similar bodies may, however, profitably be deferred to the end of the article.

Figure 22, Plate 4, shows a section parallel to the planes of stratification of the classic Scotch boghead, known as Torbanite. I owe this material as well as that of the other Scotch coals examined to the kindness of Captain Halberstadt. In this case the micro-organisms are in the condition of disorganization, which is generally found in the French bituminous schists to be discussed below. Certain faint lines are the only indication of structure presented by the light-colored bodies appearing in the microscopic field represented by the figure.

The Boghead of Autun.

Figure 23, Plate 4, shows the horizontal view of one of the micro-organisms of the boghead of Autun, first studied by Renault and Bertrand. The structure is almost obliterated by swelling and chemi-

cal metamorphosis, and only faint lines of alveolation indicate the nature of the original organization. Through the kindness of M. Bayle, Director of the Compagnie Lyonnaise des Schistes Bitumineux, I have received an abundant supply of the boghead from Autun, containing the organism described by Renault and Bertrand under the name of *Pila bibractensis.* These samples came both from the beds of Margenne and Thélots. It is an unfortunate circumstance, which beyond question has had a bearing on the views as to the nature of boghead coals, that the first of these to be minutely studied, *viz.*, that of Autun, is characterized by structural elements, which are obviously in an extremely bad condition of preservation. In none of the material which has passed under my observation have I found the component structures well organized. This seems to have been the condition of the material studied by Renault, to judge from the figures published in the atlas accompanying his work cited above. Some of the vertical sections published by Bertrand, however, present a better condition of preservation. This is notably the case in the reproduction of one of Bertrand's figures in Potonie's work on coal cited at the beginning of this article.[9] The accompanying horizontal aspect of the coal, however, presents the usual bad condition of preservation. Figure 24, Plate 4, shows a somewhat highly magnified vertical section of the boghead from Autun. In the lowermost of the organisms there is some indication of the presence of a central cavity. The walls of the structures in question are all in a swollen condition. Figure 25, Plate 5, shows a number of the individuals of Renault's *Pila bibractensis* under a low magnification. It may be stated in general of the boghead of Autun, that it is largely composed of organisms, which are in a disintegrated and swollen condition and which are consequently hard to interpret. It seems particularly unfortunate that this boghead was the first to be carefully studied microscopically.

Oil-Shale of New South Wales.

Figure 26, Plate 5, illustrates the structure of the oil-shale of New South Wales in section vertical to the plane of layering. This boghead, like those of Torbane Hill and Balbardie, Scotland, is almost completely made up of the organisms interpreted by Renault as Algae and named *Reinschia australis.* The organisms are generally not completely flattened in this plane of section and are often very much distorted and folded. The usual absence of complete flattening of the micro-organisms in bogheads composed very largely or almost entirely

[9] Potonie, op. cit., p. 23, fig. 11b.

of the disputed structures, together with the often convoluted and folded condition of these under the same condition, constitutes a strong argument against the algal nature of the latter, as it is hardly conceivable that gelatinous Algae in mass, even if preserved by a bituminous antiseptic, should have escaped complete collapse under the enormous and age-long pressure to which they have been subjected. Even so resistant a substance as wood ultimately collapses completely under pressure where it occurs as lignite. Figure 27, Plate 5, illustrates the appearance of the boghead under consideration, as viewed under a considerable magnification. The horizontal middle line of the figure is occupied by part of a single convoluted individual of *Reinschia australis*. It is a noteworthy fact that the organisms of the later bogheads, such as those of Autun and New South Wales, are very much larger in size than those found in the true Carboniferous coals of the same general structure. This contrast is illustrated clearly by a comparison of *Pila kentuckyana* or *Pila scotica* with *Pila bibractensis* or *Reinschia australis*, the two latter species being many times the dimensions of those mentioned first. Figure 28, Plate 5, shows the structure of a horizontal section of the boghead of New South Wales as viewed under a low magnification. A little above the horizontal middle line of the figure, two of the micro-organisms stand out with particular clearness. Figure 29, Plate 5, shows one of these considerably more highly magnified. The plane of section reveals both the profile and face view of the organism, showing the alveolar structure of the wall, found in all moderately well-preserved individuals. In those which have lost the usual yellowish hue and have turned some shade of brown, the structure has usually more or less completely disappeared.

The Structure of Coking Coals.

It is a well-known fact that certain coals are well adapted for coking purposes. In coals of this type when high temperatures are reached in the coking oven, the coal melts and is transformed under appropriate conditions into the substance known as coke, which is of course virtually a mineral charcoal. The property of melting, when subjected to heat, is one which is likewise characteristic of cannel and boghead coals. It has been suggested in the case of the last that the gelosic substance presented by the colonial framework of their supposed algal components is responsible for the readiness of fusion at high temperatures. Such an explanation is scarcely apposite in the case of the similarly fusible cannel coals. Even if we accept the point of view of Potonie and include the cannel coals likewise under the heading of

algal or sapropelic coals, there appears to be considerable difficulty in accounting for the fact that the supposed algal constituents in true cannel coals are either insignificant in proportion to the unquestionable spores or are entirely absent. With a view to putting the validity of the algal hypothesis of the origin of fusible coals to the test, I have examined a number of coking coals microscopically, by the same general methods as those used in the case of cannels and bogheads. It is not my intention at the present time to attempt to describe the composition of coking coals as seen under the microscope, but certain facts, however, may be appropriately referred to. In general coking coals consist of dull and bright layers, which vary as to their relative thickness and general distribution. It has been found in those cases examined that the dull portions of coking coals represent wood in a more or less modified, but still clearly recognizable condition, while the bright parts of such coals are composed of wood in a high degree of modification and disintegration. Figure 30, Plate 5, shows a horizontal section through the layering of the dull region of a coking coal, known commercially as "No. I. Pennsylvania Coking." In the middle vertical line of the figure may be seen the end of a wood tracheid, showing unquestionable bordered pits. I have found similar appearances in the dull layers of other coking coals, notably Pocahontas coal. The bright parts of coking coal present the same composition with a much greater modification, both structural and chemical, of the wood elements. It is thus apparent that there is no necessary relation between the fusibility of coal and the presence of organisms of an algal nature, since cannel coal, which has few or none of the organisms, considered to be Algae, and coking coal, which is made up entirely of the remains of wood, both are fusible coals. It should be added that the structures appearing to the right and left of the vertical middle line are likewise wood elements, although they are not clearly recognizable as such in figure 30, Plate 5.

Conclusions.

It is appropriate, after the description of the organization of boghead coals from various parts of the world and from different levels of the Paleozoic given in the foregoing paragraphs, to discuss the algal hypothesis of the origin of these coals. It may be pointed out that there is unanimity among the various observers as to the common and similar organization of the structures present in these coals. It follows that if the best preserved ones and those which by reason of their size are most easily studied in thin sections of coal, turn out not to be of algal affinities, that a similar conclusion must be applied to the re-

maining organisms, which either by reason of their large size or imperfect condition of preservation cannot be so satisfactorily subjected to microscopic investigation. It is apparently beyond question that both *Pila kentuckyana* and *Pila scotica* represent the spores of vascular cryptogams. This conclusion has been reached from the study of the numerous thin sections which are readily prepared by the methods employed in the present investigation. Abundance of material makes it clear that the bodies which have been interpreted as colonial gelatinous Algae, in reality represent certain planes of section through the rough-coated spores of vascular cryptogams. When the structures in question are cut in favorable planes and of sufficient thinness, it becomes clear that the algal semblances represent tangential sections of the rough external surface of spores of vascular plants. The real nature of the supposed Algae is further made clear by their possession of the triradiate ridge characteristic of tetrahedral spores. Moreover, in certain instances the plane of section has been observed to pass at once through the plane anterior faces and the rough, rounded external one. Further, in serial sections, which may be prepared by the methods described above, the putative Algae may be seen to present at once the alveolar appearance which has been interpreted as indicating algal affinities and the form and triradiate ridges, which clearly indicate their identity as spores of vascular cryptogams. If any further evidence were needed as to their true nature, it would be furnished by their occasional occurrence in actual tetrads, a condition which, in connection with the other data derived from the study of thin sections, makes it impossible to regard them as anything else but spores.

In the case of the larger supposed Algae the case is not so clear, on account of the distorted and often swollen condition in which they occur, as well as by reason of the difficulty of interpreting objects of greater dimensions by means of thin sections. The writers who have studied the various supposed algal structures of Paleozoic coals are, however, agreed in the conclusion that they all belong to the same category. I am myself entirely in accord with this opinion. The view of the uniformity of the organisms under discussion is further strengthened by the fact that gradations in the condition of preservation occur in the case of the larger Pilas and of Reinschia, which show clearly in the condition of best preservation the greatest resemblance to *Pila kentuckyana* and *Pila scotica.* Unfortunately it was such badly preserved species as *Pila bibractensis* and *Reinschia australis* which were first studied microscopically.

Another very important argument against the algal character of the characteristic structural constituents of so-called boghead coals is

afforded by the extreme hypotheses which this interpretation demands. For example, M. Bertrand in his work cited above [10] states that the oil-shale of New South Wales, forming a layer fifteen feet in thickness, composed practically entirely of the organisms known as *Reinschia australis*, must have been laid down a single season during a period of low water. He makes similar statements in regard to the thick bituminous deposits of Autun. It is inconceivable that such a huge mass of algal matter, which in its fresh condition must have been enormously greater in volume, should have been accumulated and synchronously preserved in so short a time. The problem of the preservation of this great amount of gelosic substance is not rendered easier by the supposition that the antiseptic was bituminous in its character and consequently must have been poorly soluble or quite insoluble in water. It is easy to imagine the preservation of logs and even of the harder parts of animals in asphaltic lakes, such as have been found in California, South America and certain of the West Indian Islands; but the best developed scientific imagination would find it difficult to picture enormous masses of gelatinous matter, impregnated rapidly and completely by preservatives of a bituminous nature. It moreover seems clear that the intervention of bituminous matter in the process of the formation of such coals from gelatinous Algae is absolutely essential, for as Bertrand has pointed out, the contraction in the organisms constituting boghead coals although great (from 1/7 to 1/24 in volume), would only correspond to a proportion of gelatinous substance from 105 to 360 *per mille;* whereas the amount of gelatin in ordinary dry commercial gelatin is from 700 to 800 *per mille*. He concluded that the deficiency must be made up by the infiltrated bituminous matter.

Further, even if it be granted that bituminous matter actually enters into the transformation of gelatinous Algae into boghead coals as the hypothesis originated and elaborated by Renault, Bertrand and Potonie demands, the question of the origin of this substance in connection with large accumulations of Algae in widely separated parts of the world and at remote geological epochs constitutes a very grave difficulty. It has been variously suggested that the bituminous substance originates from the remains of animals or from a transformation of a part of the algal substance itself into bituminous matter. In view of the relatively insignificant amount of animal matter compared with vegetable matter on the surface of the world at the present time we are scarcely justified in drawing the inference that the remains of animals

[10] Charbons Humiques et Charbons de Purins, p. 2.

gave rise to bitumen, especially as there is every reason to believe that the disproportion between animal and vegetable matter must have been very much greater in the Paleozoic than in the present epoch. If the Algae themselves gave rise to the bituminous matter, we would expect to find them locally more or less completely transformed into this substance. No cases of this kind exist so far as I am aware.

Another strong argument against the algal hypothesis of the origin of boghead coals is the fact that cannel coals, which are practically identical with them in chemical composition, are recognized to be composed predominantly of the spores of vascular cryptogams. Potonie[11] recognizes this identity of origin of cannel and boghead coals, since he states that they are both "sapropelic" in their nature, that is, they were both laid down in open quiet water and are both bituminous in their chemical composition. It is not open to doubt that the bituminous character of cannel coal is mainly, if not entirely, due to the enormous quantities of the remains of resinous spores of vascular cryptogams which it contains. Boghead coals are like cannel coals in their chemical composition, differing only in the more richly bituminous characteristics, which they present. As has been pointed out in the foregoing paragraphs, they are likewise notable for the greater proportion of substance showing structure under the microscope. There appears in fact to be a definite relation between the amount of structural elements and the proportion of bituminous matter found in such coals. It appears clear from the description of the micro-organisms of boghead coals, especially such of these as show them in a comparatively good condition of preservation, that the bodies in question represent the spores (in most cases apparently the macrospores) of vascular cryptogams. The greater concentration of the bituminous substance in so-called boghead coals, moreover, is related to a much scantier occurrence of such coals, which, as compared with cannels, occur in beds of very restricted area.

Apparently as a result of all the considerations brought forward in the statement of the conclusions drawn from the present investigation, we must regard the so-called boghead coals as essentially composed of the remains of spores of vascular cryptogams and thus as closely resembling cannels, which they in general differ from, only in the greater concentration and larger size of the constituent spores. The less abundant occurrence and more purely sporal composition of boghead coals is doubtless to be attributed to the nature of the component

[11] Entstehung d. Steinkohle u. Verwandter Bildungen, Einschliesslich des Petroleums, p. 20.

spores, which in contrast to those occurring in cannels are predominantly of large size, and are as a consequence in all probability to be regarded as macrospores. The tendency of water action, under which it is universally agreed both cannels and bogheads were laid down, would be to bring about a greater degree of concentration of the larger and heavier bodies, the macrospores.

At the present time the algal hypothesis is applied not only to the origin of boghead coals, but is extended also to the question of the origin of petroleum. If we assume that those bodies, which afford on distillation the greatest amount of petroleum, are as it were the mother substance of petroleum, the conclusion cannot be avoided that boghead coals and similar substances are the source of petroleum-like compounds. As has been pointed out above, we cannot with a due consideration of the microscopic structure of boghead coals regard them as composed of remains of Algae. The algal hypothesis of the origin of petroleum consequently, so far as it rests on the structural components of bogheads, falls to the ground. It is further invalidated by the relatively small quantities of boghead coals found throughout the world. The result of the present investigations is to show that bogheads are essentially similar in their composition to the much more abundant cannels. Consequently we are able to draw not only on the structure of the relatively small amounts of boghead coals for a hypothesis as to the origin of petroleum, but also upon the relatively abundant cannels, which are widely distributed in the Northern Hemisphere, where petroleum deposits are likewise abundant. The conclusion appears obvious that the innumerable spores of Paleozoic Pteridophyta laid down in enormous quantities on the bottoms of the shallow lakes or lagoons, in which the Coal Period proper abounded, have furnished the raw material from which in the course of countless years, as a result of great pressure and perhaps of high temperature as well, the enormously valuable petroleum products have been elaborated.

The discussion of the possibility of the formation of algal peats under modern conditions has not been entered upon in the present article because that subject will be considered in a subsequent communication.

Summary.

1. The organisms found in abundance in boghead coals are not of the nature of colonial gelatinous Algae, as has been asserted by Renault, Bertrand and Potonie on the basis of the examination of a small number of insufficiently thin sections of such coals.

2. The bodies in question, as revealed in thin serial sections, made

by improved technique on the microtome, are spores of vascular cryptogams.

3. The proof that the constituent micro-organisms of boghead coals are not Algae but spores, overthrows the algal hypothesis of the origin of petroleum and similar substances.

4. It appears clear that petroleum products have been derived, mainly at any rate, from the waxy and resinous spores of vascular cryptogams laid down on the bottoms of the shallow lakes of the Coal Period. These lacustrine layers, either as cannels, bogheads or bituminous shales, according to the sporal composition and the admixture of earthy matter, are the mother substance of petroleum. Pressure and temperature either separately or combined, in the presence of permeable strata, have brought about the distillation of petroleum from such deposits.

EXPLANATION OF THE PLATES.

PLATE 1.

FIGURE 1. Vertical section of Kentucky cannel coal. (× 180.)

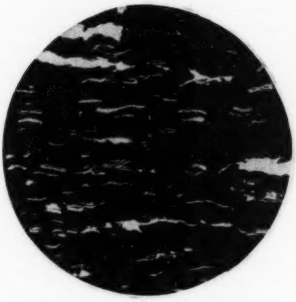
FIGURE 2. Horizontal section of Kentucky cannel coal. (× 180.)

FIGURE 3. Horizontal section of Kentucky boghead coal, showing the supposed colonial Alga, *Pila kentuckyana*. (× 180.)

FIGURE 4. Horizontal section of another preparation of the same. (× 40.)

FIGURE 5. Part of Figure 4 more highly magnified. (× 120.)

FIGURE 6. The same showing another part. (× 120.)



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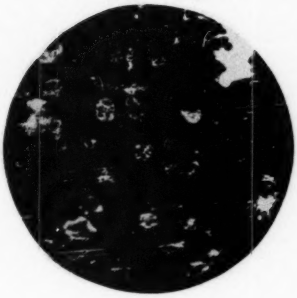

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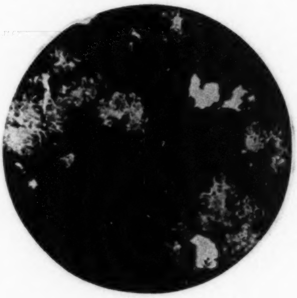

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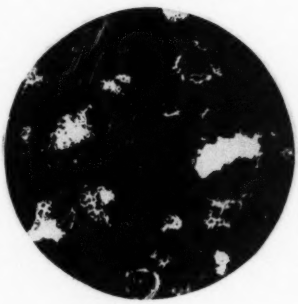

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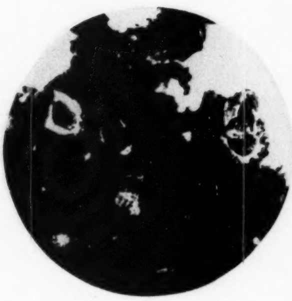

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PLATE 2.

FIGURE 7. Part of the same. (× 180.)

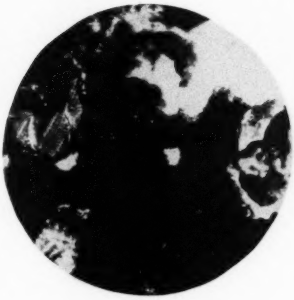
FIGURE 8. Part of another horizontal section showing *Pila kentuckyana.* (× 120.)

FIGURE 9. More highly magnified view of the same showing a tetrad of spores. (× 180.)

FIGURE 10. Another horizontal section of the same showing spores and the supposed Algæ. (× 180.)

FIGURE 11. Another of the same showing a very characteristic spore and a considerable number of the supposed Algæ. (× 180.)

FIGURE 12. Another preparation of the same, showing a spore-like body and fragments of numerous supposititious Algæ. (× 180.)



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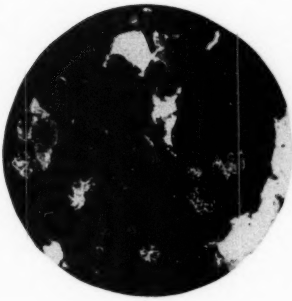

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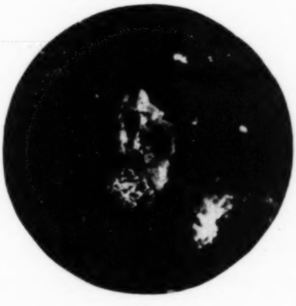

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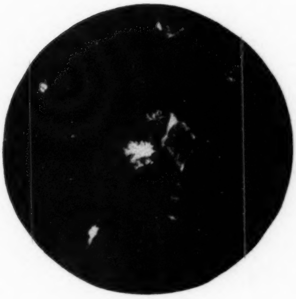

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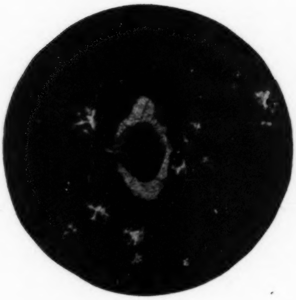

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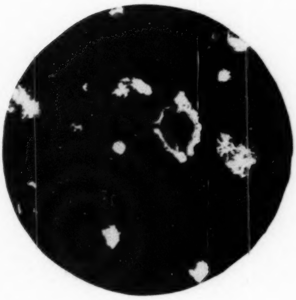

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PLATE 3.

Figure 13. Another of the same showing one spore with triradiate ridge and other spores and supposed Algæ. (× 180.)

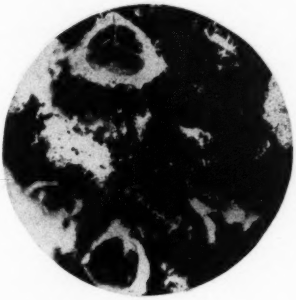
Figure 14. A spore of the same highly magnified. (× 500.)

Figure 15. A tetrad of the same. (× 180.)

Figure 16. Horizontal section showing numerous examples of *Pila scotica*, some in tetrads. (× 130.)

Figure 17. Upper portion of Figure 16 more highly magnified. (× 180.)

Figure 18. Vertical section of boghead from Balbardie, Scotland. (× 120.)



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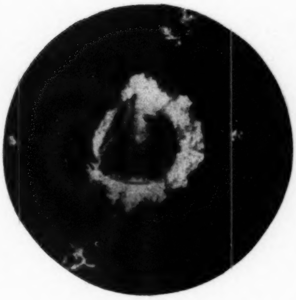

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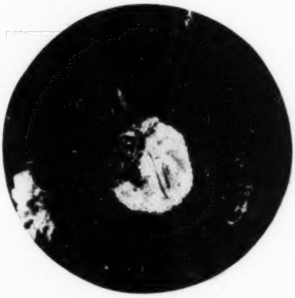

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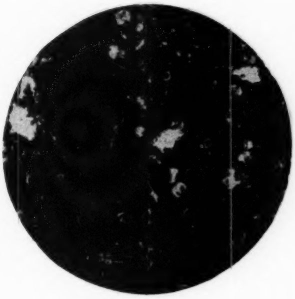

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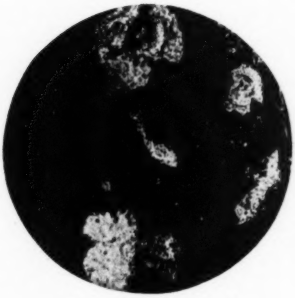

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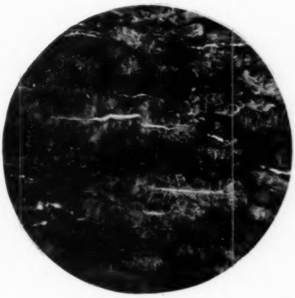

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PLATE 4.

FIGURE 19. Another of the same. (× 120.)

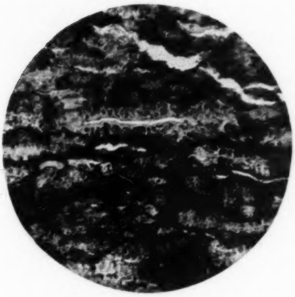
FIGURE 20. Horizontal section of the same. (× 120.)

FIGURE 21. Horizontal section of the same. (× 180.)

FIGURE 22. Horizontal section of Torbanite. (× 120.)

FIGURE 23. Horizontal section of boghead from Autun. (× 120.)

FIGURE 24. Vertical section of boghead from Autun. (× 120.)



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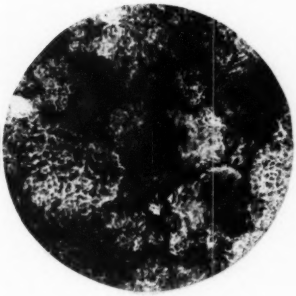

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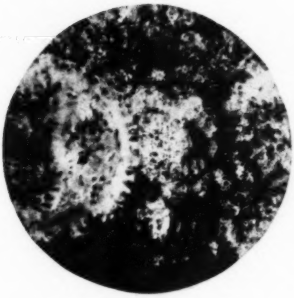

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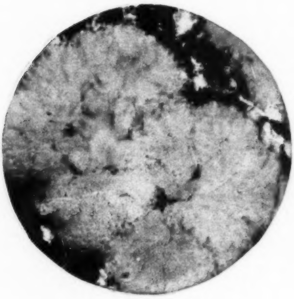

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PLATE 5.

FIGURE 25. Horizontal section of boghead from Autun. (× 80.)

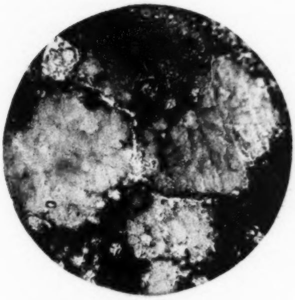
FIGURE 26. — Vertical section of oil-shale from New South Wales, showing masses of *Reinschia australis*. (× 40.)

FIGURE 26. Part of the same more highly magnified. (× 180.)

FIGURE 28. Horizontal section of oil-shale from New South Wales. (× 40.)

FIGURE 29. Part of the same. (× 120.)

FIGURE 30. Horizontal section of Pennsylvania coking coal showing presence of wood elements. (× 180.)



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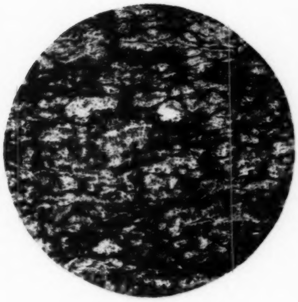

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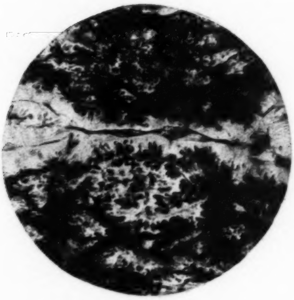

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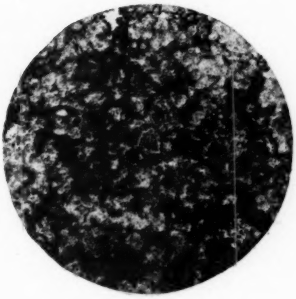

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